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## HIGH EXPLOSIVE TESTING OF HARDENED AIRCRAFT SHELTERS

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## ABSTRACT

Two full-size, hardened, third-generation aircraft shelters of the type employed by the U.S. Air Force in Europe and by NATO countries were subjected to a series of five high explosive tests. The purpose of the tests (nicknamed DISTANT RUNNER) was to gather empirical data necessary for the Department of Defense Explosives Safety Board to reduce existing explosives quantity-distance safety standards for storage of conventional munitions in and near hardened aircraft shelters. The first two tests each used a 120-ton explosive stack of ANFO located external to the shelters. The other three tests consisted of internal detonations of AIM-9 warheads and Mark-82 bombs. As a result of these tests the DDESB has reduced certain quantity-distance safety standards. As a bonus, a large amount of structural response data was gathered which can be applied to problems involving dynamic loading of reinforced concrete structures.

## INTRODUCTION

In Europe, real estate restrictions and property constraints pose difficulties in placing aircraft shelters and munitions storage areas within U.S. Air Force and NATO aircraft bases. Overly restrictive safety criteria may compromise military operations and readiness. Under sponsorship of the Department of Defense Explosives Safety Board, the Defense Nuclear Agency conducted a series of five high explosives tests, involving two full-size aircraft shelters, with the goal of obtaining data which would allow the reduction of certain established quantity-distance (QD) safety standards. The tests were conducted at White Sands Missile Range, New Mexico, during September to November 1981.

Quantity-distance standards are expressed according to the equation,  $D = KW^{1/3}$ , where D is the safe distance from a weight, W, of mass-detonating explosives. K is the QD factor, or safe scaled distance, investigated by this test series. At the time of the tests a QD factor of 30 ft/lb<sup>1/3</sup> (16m/kg<sup>1/3</sup>) was applied to military aircraft parked in the open and in shelters. A standard of 40 ft/lb<sup>1/3</sup> (16m/kg<sup>1/3</sup>) was applied as the scaled distance required to separate explosive storage from public areas, subject to minimums required for protection against fragments. The QD factor applied to an aircraft parked within a shelter was

taken to be the same as for an aircraft parked in the open. One objective of these tests was to demonstrate that the QD factor could be decreased for sheltered aircraft due to the protection afforded by the shelter. A second objective was to show that the QD factor of 18 applied to runways could be substantially reduced. The third major objective was to assess the response of the third-generation shelter to various sizes of internal detonations in terms of airblast and fragmentation propagated outward from the shelter.

## PROCEDURE

Construction

Two full-size third generation aircraft shelters with adjoining taxiways were constructed on a remote test site on the northern part of White Sands Missile Range. The shelters were structurally identical to those constructed in Europe by the U.S. Air Force and by NATO countries except for two minor details: the electrical motors normally used to open the front doors were omitted and the shelter foundations were slightly wider to accommodate the load-bearing properties of the soil at the test site. Construction took 11 months. The quonset-shaped shelters were constructed of highly reinforced concrete and were designed to accommodate one fighter aircraft. The arched walls were approximately two feet thick with various colors of concrete to aid in identification of debris following destructive testing (Fig. 1). The two sliding front doors were one foot thick and each weighed 100 tons. An exhaust port at the rear of the shelter could be closed off by two large sliding doors.

Instrumentation

Free field instrumentation in the test area surrounding the shelters consisted of 44 air blast pressure gages and 33 triaxial accelerometers for ground motion (Fig. 2). Each shelter was instrumented with approximately 30 blast pressure gages and a dozen or so biaxial accelerometers to record the pressure environment and the resulting dynamic structural response. Passive strain measurements, to document permanent deformation of the shelters from the external explosions, were taken by measuring pretest and post-test positions of

50 punch marks on each of four arch ribs. High speed technical photography was used to document each test. Eight aerial cameras and up to 33 ground-based cameras recorded shelter motion and explosives performance. A comprehensive program for measuring debris was conducted. Following the external explosions, the density of soil ejecta which landed on the taxiways was measured. Following the destructive internal explosions, previously cleared ground sectors surrounding the shelters were surveyed for shelter fragments which were then counted and weighed. Data from gages was recorded using a Digital Encoding System installed in a bunker near the test bed. Two hundred data channels were amplified, digitized, and multiplexed in the bunker and sent via coaxial cable to the instrumentation van located one mile from the test bed where the data was recorded on magnetic tape. A calibration test consisting of 1200 lb of ammonium nitrate and fuel oil explosive was detonated prior to the main test series and verified that the instrumentation system was working properly.

#### EXTERNAL EXPLOSIONS

##### Description

The first two explosions in the DISTANT RUNNER test series each used a 120-ton stack of ANFO (a mixture of ammonium nitrate and fuel oil) as the explosive located external to the shelters. An obsolete F-101B fighter plane was positioned in each shelter. The primary objective of the test was to demonstrate that at an incident overpressure of 15 psi, leakage airblast inside the closed shelters would be less than 1.7 psi. A second objective was to test the taxiway at a scaled distance  $4 \text{ ft/lb}^{1/3}$  from the explosion. The first test subjected shelter B to a side-on blast and shelter A to a rear-on blast, both at a nominal 15 psi. The second test, conducted a month later, subjected shelter A to a nominal 15 psi front-on while shelter B received 7 psi from an angle 27 degrees off of front-on. These tests were designated as Event 2 and Event 3. (Event 1 was rescheduled to occur between Events 4 and 5. The original designators were kept despite the resequencing.)

##### Results: Event 2 and 3

No structural damage occurred to the concrete arches or rear walls. Both rear exhaust doors were blown down (inward) on the shelter with its rear to the blast. The tail of the F-101B was damaged considerably by one of the flying doors. The front doors of this shelter were not damaged. One rear exhaust door of the shelter oriented side-on to the blast was blown down but did not strike the aircraft. Several bolts securing the roller mechanism on the front doors broke, but the doors stayed on their tracks.

Based upon free field air blast measurements the desired nominal environment of 15 psi was produced on both external tests (Fig. 3). Pressure build-up inside the shelters was measured to be less than 1.6 psi except for one location in the corner near the front door of the shelter exposed side-on to the blast. A pressure in excess of 8 psi was recorded there, but was evidently a very localized high pressure region which dissipated before reaching the next gage only 20 feet away.

#### INTERNAL EXPLOSIONS

##### Description

Following the two external tests, three internal tests were conducted. The explosives used are listed in the Table. The objectives of the internal tests were: assess blast suppression by the shelters, assess debris patterns with regards to safety criteria, and observe the failure mode of the shelter.

##### Results: Event 4

The shelter and aircraft were completely destroyed in Event 4. High speed photography showed that the arch was first lifted off its foundation and then split longitudinally along the crown. As a result the entire right half (as viewed from the front) of the arch was launched into the air and traveled 200 feet as a unit. The break-up of the left half of the arch was influenced by the personnel door entry way. Several large sections impacted at ranges of 100-200 feet. The rear of the shelter suffered extreme damage, but on the whole was displaced only several feet. The front doors were blown directly forward and traveled about 400 feet. High speed photography showed them tumbling top-over bottom. One front door came to rest against the other shelter causing only superficial gashes on its side.

TABLE  
INTERNAL EXPLOSIONS

Event 4:	12 MARK-82 bombs 2292 lb Tritonal 30 lb C-4 2 lb PETN
Event 1:	4 AIM-9 air-to-air missiles 42 lb HBX-1 6 lb C-4 .6 lb PETN
Event 5:	48 Mark-82 bombs 9168 lb Tritonal 64 lb C-4 9 lb PETN

A ground survey of debris (Fig. 4) indicates that 90% of the debris was contained in large pieces at ranges less than 250 feet from the shelter (except for the front doors). The debris with the longest range came from the metal ring beam on the front face of the arch. Beam sections were projected forward in a 180-degree fan with ranges of 1000 to 1700 feet.

Initial failure of the shelter along the arch-foundation interface and complete destruction of the shelter were consistent with pre-shot calculations. Blast pressures to the rear were attenuated slightly by the shelter, while blast pressures forward and to the sides showed no attenuation effects (Fig. 5). Consequently, a reduction in the quantity-distance factor for internal explosive storage does not appear to be indicated. The failure of the shelter to attenuate the blast laterally can be ascribed to the initial failure mode of the shelter along the foundation. By strengthening the arch-foundation connection (rebar) it should be possible to cause initial failure to occur at the crown with consequent upward (rather than lateral) venting of the blast.

#### Results: Event 1

The four AIM-9 warheads were two feet above the floor positioned as if they were on an aircraft. No aircraft was in the shelter. As a result of the explosion the two front doors were blown evenly outward about 20 feet with no major damage. The blast deflectors, which normally might have restricted this motion, had been broken off from the bottom of the doors by a previous test. The shelter suffered no structural damage. All shrapnel was contained by the shelter, although the warhead base plates punched through the rear doors and struck the rear wall of the exhaust port. The personnel door was undamaged and remained closed. Airblast was effectively suppressed.

#### Results: Event 5

Twelve bombs were positioned beneath an F-101B. Another 36 bombs were positioned near the aircraft and at the front corners of the shelter to simulate weapon storage. As expected, the shelter was completely destroyed. In general the debris pattern was similar to that from Event 4, but the fragments were smaller and had larger ranges. Sections of the front doors were scattered between 400 and 1200 feet directly forward of the shelter. The arch was fragmented into several large pieces which landed at ranges of 100-300 feet. Numerous smaller chunks had ranges up to 1200 feet. The rear of the shelter was completely demolished and leveled. Sections of the front ring beam were found at roughly the same ranges as for Event 4. They were not thrown further by the larger explosion because the greater force distorted their aerodynamic shapes causing increased drag during their flight.

Blast overpressures (Fig. 6) were slightly suppressed by the shelter to the rear and to a lesser extent to the front of the shelter. No suppression was observed in the lateral directions. Consequently, a reduction in the current airblast quantity-distance criteria for internal explosives is not expected. Debris patterns from this test and Event 4 are being carefully evaluated with regard to the other safety hazard, flying debris.

#### CONCLUSION

The DISTANT RUNNER test series was highly successful. The primary objective of experimentally verifying that certain quantity-distance safety standards could be reduced was met. The DOD Explosive Safety Board has reduced the QD factor from  $30 \text{ ft/lb}^{1/3}$  to 5 for aircraft shelters near munitions storage igloos, and to 8 for aircraft shelters near open storage sites. The DDESB has also recommended these changes to NATO Subgroup AC/258. As another result of the tests, structural modifications have been identified and are under study which would increase the strength of the shelters.

A large amount of technical data which was gathered from the tests can be applied to the analysis of structural response to blast loading. The tested shelters were full size, so the problem of scaling was avoided. Companion measurements of airblast loading and the resulting dynamic structural response were made which can be used to evaluate dynamic modeling techniques (Fig. 7 & 8). Post-test measurements on permanent building deformation can be used in developing and checking methods for modeling inelastic deformations (Fig. 9). An extensive effort was expended collecting and analyzing debris fragments produced by the destructive tests. Thousands of fragments were surveyed, weighed, and measured. These data can be applied toward the study of fragment size distribution functions and ranges. The details of DISTANT RUNNER testing and a summary of technical results are presented in the References.

#### REFERENCES\*

1. "DISTANT RUNNER Test Execution Report" POR 7062, Defense Nuclear Agency, 29 Jan 1982.
2. "Proceedings of the DISTANT RUNNER Symposium" POR 7063, Defense Nuclear Agency, 2 Sep 1982.
3. "DISTANT RUNNER Test Program Final Report" Defense Nuclear Agency, In Preparation.

\*Distribution limited to U.S. Government agencies only. Other requests must be referred to the Defense Nuclear Agency, Washington, DC 20305.

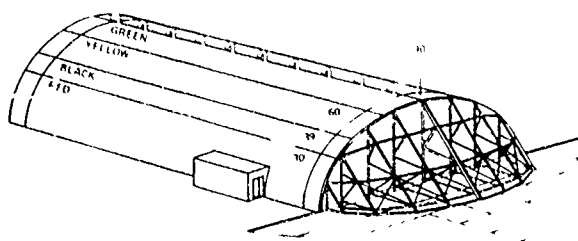


Figure 1. Third Generation Aircraft Shelter

○ BLAST PRESSURE GAGE  
▲ TRIAXIAL ACCELEROMETERS

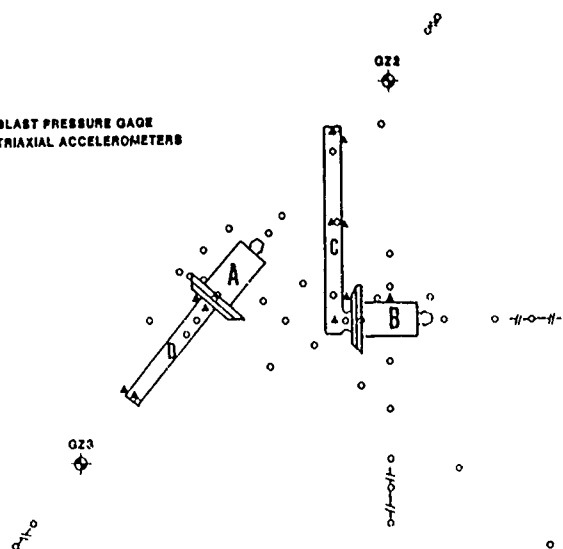


Figure 2. Free-Field Gage Locations

### DISTANT RUNNER EVENT 2 — BLAST ENVIRONMENT

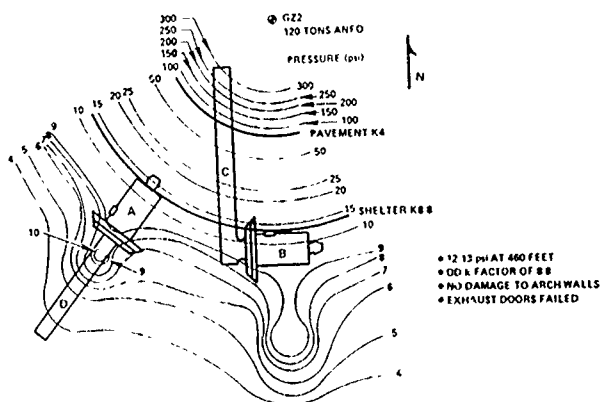


Figure 3. Event 2 Peak Pressure Contours

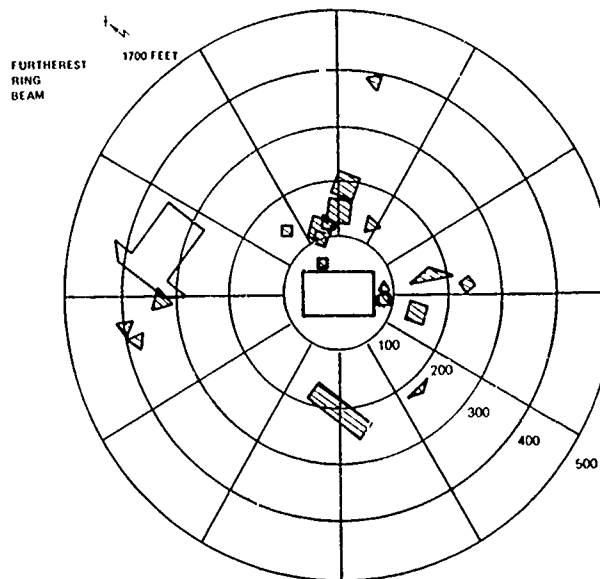


Figure 4. Event 4 Large Debris Map

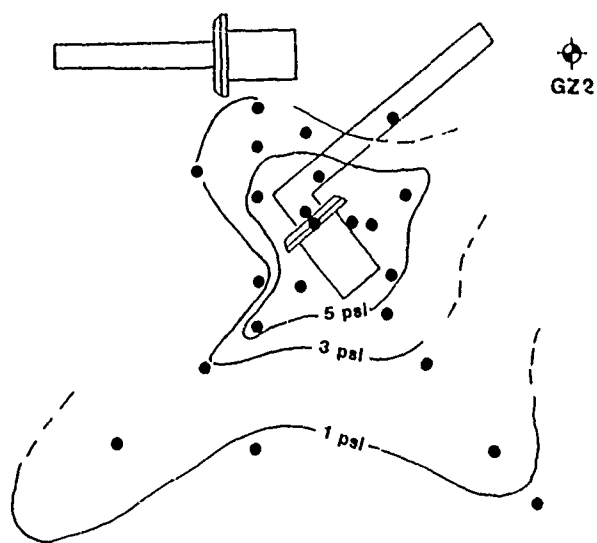


Figure 5. Event 4 Peak Pressure Contours

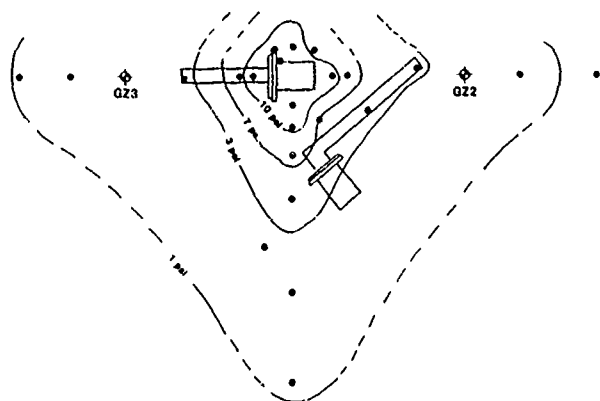


Figure 6. Event 5 Peak Pressure Contours

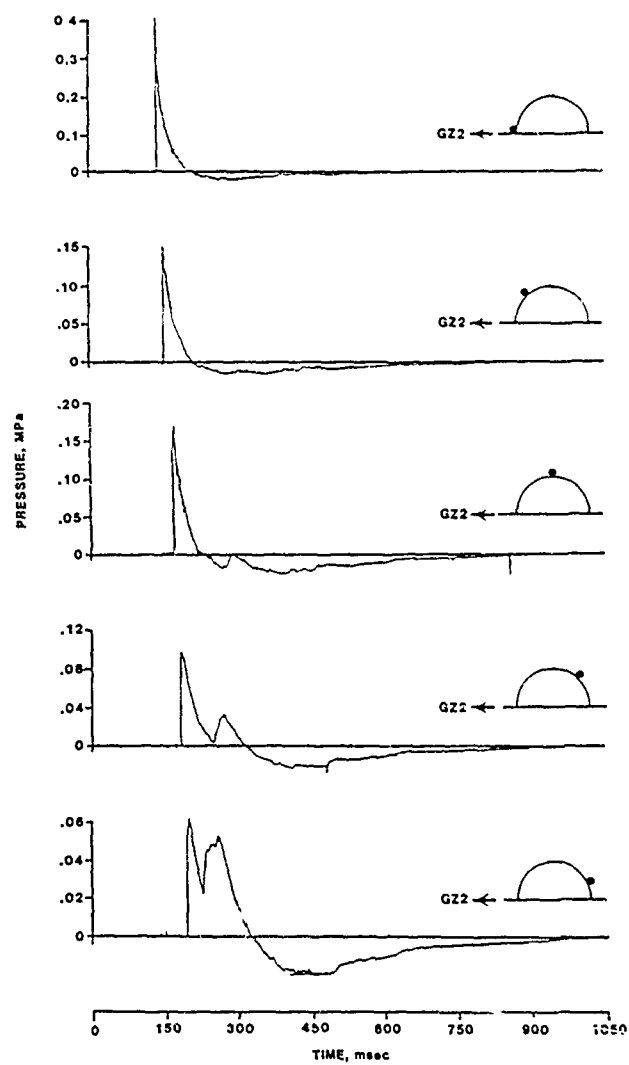


Figure 7. Event 2 - Shelter B External Pressures

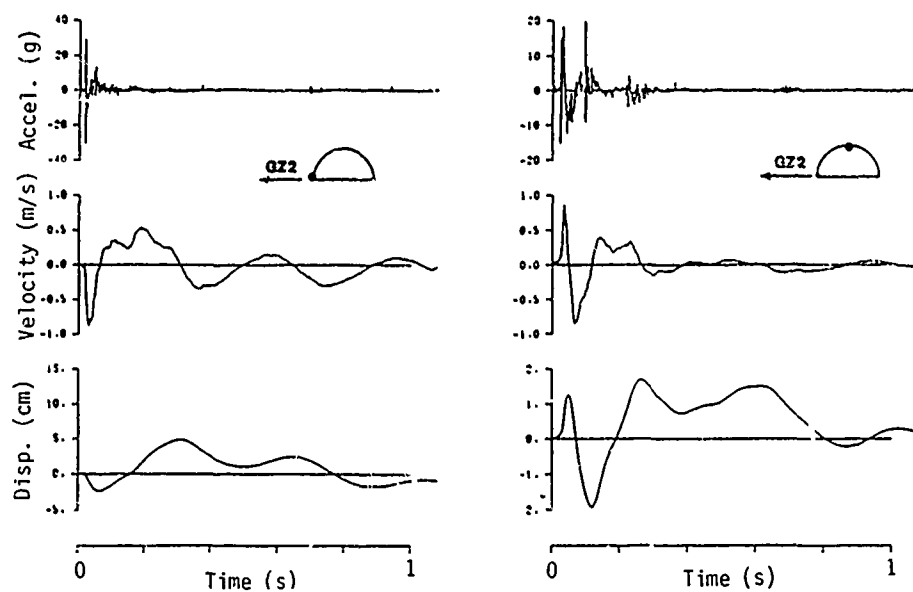


Figure 8. Event 2 - Shelter B Wall Motions

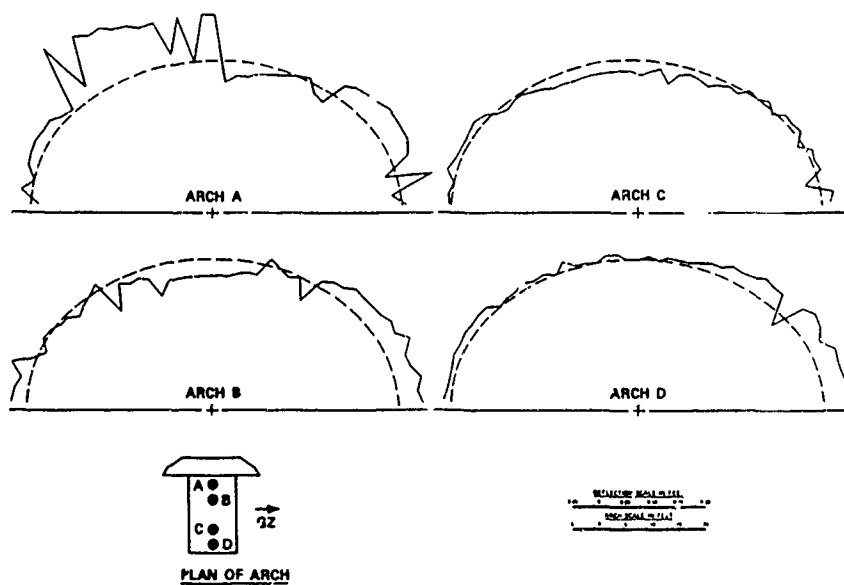


Figure 9. Event 2 - Shelter C Permanent Radial Deformation